

Soil Profile Distribution of Phosphorus and Other Nutrients following Wetland Conversion to Beef Cattle Pasture

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ABSTRACT

Largely influenced by the passage of the Swamp Land Act of 1849, many wetlands were lost in the coastal plain region of the southeastern United States, primarily as a result of drainage for agricultural activities. To better understand the chemical response of soils during wetland conversion, soil core samples were collected from the converted beef cattle pastures and from the natural wetland at Plant City, FL in the summers of 2002 and 2003. Data collected from the natural wetland sites were used as reference data to detect potential changes in soil properties associated with the conversion of wetlands to improved beef cattle (*Bos taurus*) pastures from 1940 to 2003. The average concentration of total phosphorus (TP) in pasture soils (284 mg kg^{-1}) was significantly ($p \leq 0.001$) lower than its levels in natural wetland soils (688 mg kg^{-1}). Compared with the adjoining natural wetlands, the beef cattle pasture soils, 63 yr after being drained exhibited: (1) a decrease in TOC (-172 g kg^{-1}), TN (-10 g kg^{-1}), K (-0.7 mg kg^{-1}), and Al (-130 mg kg^{-1}); (2) an increase in soil pH (+1.8), Ca ($+88 \text{ mg kg}^{-1}$), Mg ($+7.5 \text{ mg kg}^{-1}$), Mn ($+0.3 \text{ mg kg}^{-1}$), and Fe ($+6.9 \text{ mg kg}^{-1}$); and (3) no significant change in Na, Zn, and Cu. Wetland soils had higher concentrations (mg kg^{-1}) of Al-P (435), CaMg-P (42), FeMn-P (43), and Org-P (162) than those of 172, 11, 11, and 84 mg kg^{-1} , respectively, found in the pasture soils. The levels of water-soluble P and KCl-bound P were comparable between wetland and pasture soils in 2003. Results of this study therefore suggest that wetland conversion to beef cattle pastures did not function as a source of nutrients, especially P and N, even with manure and urine additions due to the presence of grazing cattle.

WITH THE ADOPTION OF THE CONCEPT OF RESTORATION and creation of wetlands as the first line of defense to mitigate unavoidable wetland loss, there is a serious need to understand the historical condition and chemical and/or biological functions of ecosystems following a conversion from wetlands to agricultural use. Conversion of wetlands to agricultural use can be significant at both the local and global scale (Reiners et al., 1994). Some of the expected local and global changes include: (1) hydrology and sediment transport (Meher-Homji, 1991); (2) global carbon budget (Houghton, 1991); (3) soil properties (Spaans et al., 1989); (4) sustainable productivity (Sinha and Swaminathan, 1991); (5) land-atmosphere climate interactions (Salati and Nobre, 1991; Dale, 1997); and (6) increases or decreases in biodiversity, productivity, migration, and sustainability (Turner et al., 1991).

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Basic information on the ecological understanding of the responses of systems to water regime change is essential in both the rehabilitation and creation of wetlands. Progress in this area may facilitate some reversal of loss of wetlands in the future. This can only be accomplished if our understanding of the effects of water regime changes in wetlands continues to improve and is communicated so that it can influence mindset and proactive management actions. Consequently, the way pasture management and hydrology interact to affect nutrient dynamics and water quality is still important to environmentalists, ranchers, and public officials. Beef cattle operations have been suggested as one of the major sources of nonpoint source P pollution that is contributing to the degradation of water quality in lakes, rivers, and groundwater aquifers in southern Florida (Sigua et al., 2006).

Wetland soils are characterized by slow turnover of organic material due to limited supply of terminal electron acceptors (Fisher and Reddy, 2001). The mineralization of organic matter and subsequent release of P is predominately controlled by the quantity of organic materials (Godshalk and Wetzel, 1978) and the supply of electron acceptors (D'Angelo and Reddy, 1994). The higher concentration of TP in natural wetlands can be attributed to wetland functions within the ecosystem. Wetland soils can function as sinks for P. This has environmental implications because wetlands may accumulate organic matter over time. Although several studies (Mortiner, 1941; Ponnamperna, 1972; Patrick and Khalid, 1974; Gale et al., 1992; Moore and Reddy, 1994) have shown that P is released to soil solution under anoxic conditions, the actual mobility and release of various forms of P from drained wetland surface soils have received little attention. The dynamics of P cycling are completely different under aerobic and anaerobic conditions.

While P is being released due to the reduction of Fe oxides and solubilization of sorbed P during anoxic conditions, there is the potential for P to be removed from solution through coprecipitation with or sorption on freshly precipitated Fe oxides during aerobic conditions. Twinch (1987) found that drying of soils could reduce both the buffer capacity and bioavailable P concentrations, but could increase equilibrium P concentrations by a factor of three, thereby increasing the P release

Abbreviations: TOC, total organic carbon; TP, total phosphorus; TN, total nitrogen; WSP, water-soluble phosphorus; KCl-P, potassium-bound phosphorus; Al-P, aluminum-bound phosphorus; FeMn-P, iron manganese-bound phosphorus; CaMg-P, calcium magnesium-bound phosphorus; Org-P, organic-bound phosphorus; MCP, McIntosh pasture sites; MCW, McIntosh wetland sites; GLM, general linear model; LSD, least significant difference; BMP, best management practice; SOM, soil organic matter.

potential of dried soils. Thus, any effort to model P transformations and mobility in the environment that fails to account for the effects of changing hydrology may poorly estimate the movement and dynamics of P in the environment. Hence, the ecological impact of wetland conversion must be fully considered. There is a need for further research to evaluate and compare the cumulative impacts of draining wetlands on changes in productivity and soil chemical properties. We hypothesized that conversion of natural wetland to beef cattle pasture may increase the levels of soil nutrients, especially P due to cattle grazing. To verify our hypothesis,

we assessed the soil profile distribution of P and other nutrients following the conversion of a natural wetland to beef cattle pasture in southwestern Florida.

MATERIALS AND METHODS

Site Description

This study was conducted on a 41-ha site within a 162-ha historic wetland that was largely drained and converted to a beef cattle pasture in the early 1940s. Cattle production at the study site is forage-based with bahiagrass (*Paspalum notatum*, Flügge). Pastures were fertilized annually with 90 kg N, and P-

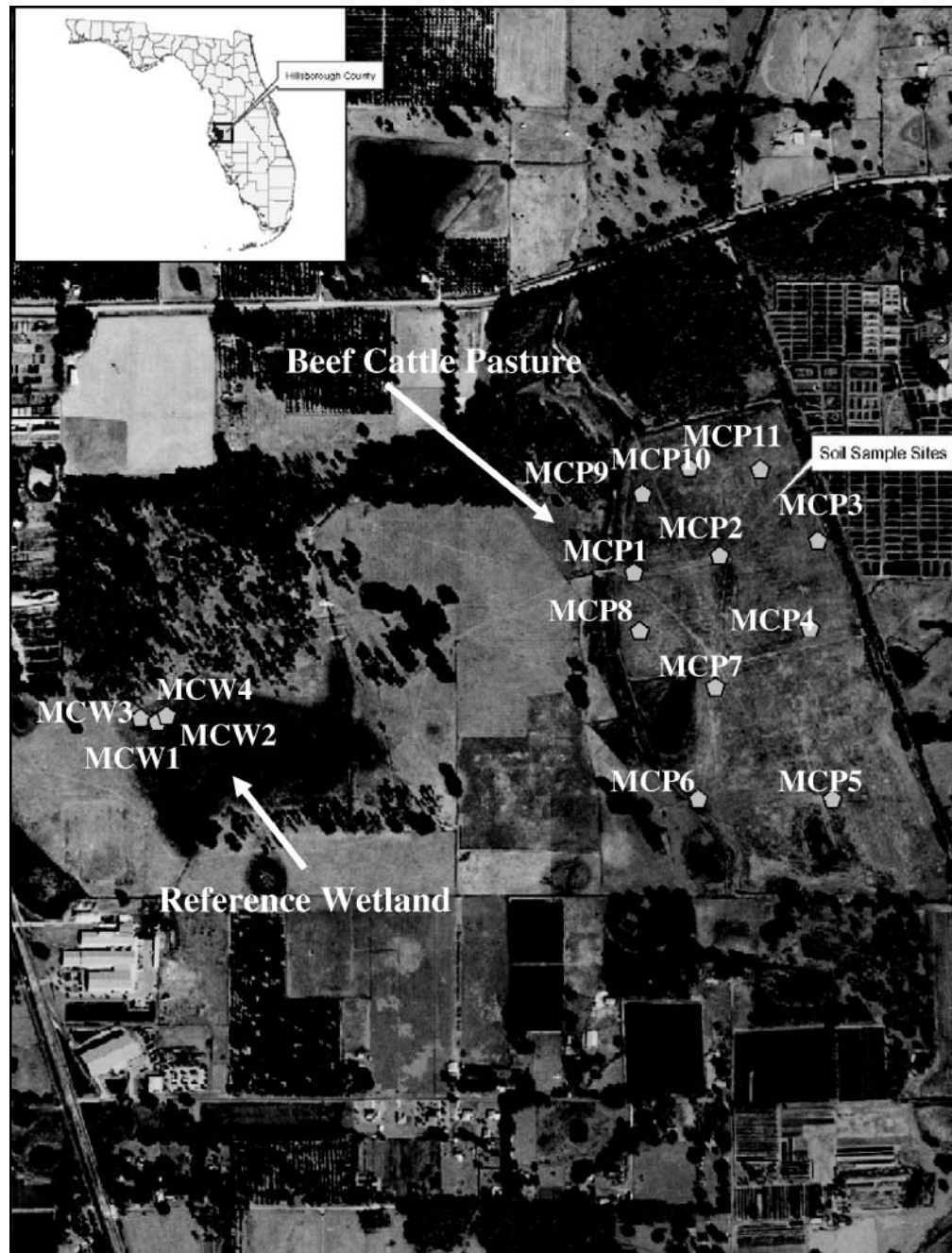


Fig. 1. Location of study site and soil sampling sites (beef cattle pastures, McIntosh pasture sites (MCP), and natural wetland, McIntosh wetland sites (MCW)).

(13 kg ha⁻¹) and K- (37 kg ha⁻¹) containing fertilizers were applied once every 3 yr. Fertilizer application that began in 1985 was stopped in 2001 (Jim Griffin, personal communication, 2003). The converted beef cattle pasture and the reference-adjointing natural wetland are now a part of a Hillsborough County Environmental Land Acquisition and Protection Program parcel owned by the city of Plant City, Florida. The site is located in northeastern Hillsborough County (Sections 4, 5, 8, and 9, Township 28 South, and Range 22 East, just southeast of the intersection of State Road 39 and Knights Griffin Road), Florida, bounded on the east by the Eastside Canal and on the west by ditch and berm systems. The different sampling sites are shown in Fig. 1 (Beef Cattle Pasture Sites, MCP: 28°4'18.3000" N to 28°4'8.1040" N and 82°7'24.8880" W to 82°7'16.5000" W and Natural Wetland Sites, MCW: 28°4'8.6160" N to 28°4'8.9400" N and 82°7'57.6120" W to 82°7'55.9920" W). The pastures are now being converted into an enhanced stormwater wetland to remove P and primary pollutants from stormwater originating from 2400-ha mixed land use catchments within the Hillsborough River watershed. Beef cattle were removed from the pastures and cattle grazing totally ceased in the spring of 2003.

The study sites consist of deep, very poorly drained soils on well-decomposed organic matter underlain by sandy marine sediment and are described as sandy skeletal, siliceous, dysic, hyperthermic Terric Medisaprist (Doolittle et al., 1989). Soil samples taken from pasture fields had higher average bulk density of 1.05 Mg m⁻³ when compared with 0.48 Mg m⁻³ for soil samples from the adjoining natural wetlands. The wide variations of soil bulk density between the beef cattle pasture and wetland could be attributed to the higher concentration of organic matter in wetland sites. Particle size analyses of soils from pasture and wetland were: 850, 125, and 25 g kg⁻¹ and 910, 50, and 40 g kg⁻¹ of sand, clay, and silt, respectively. The particle-size distribution of the soils indicated that initially at most locations the inherent soil properties in the natural wetlands and converted beef cattle pasture were similar, hence avoiding bias and unreliable comparisons of soil properties (Wall and Hytonen, 2005). The average annual precipitation (1993 through 2005) in the study site was 1435 mm, with approximately half of this amount occurring during the months of June through September.

Soil Sampling

To better understand the chemical response of soils during wetland conversion to beef cattle pasture, soil samples were collected from the beef cattle pastures and from the adjoining natural wetland. Soil core (0–20; 20–40; 40–60; and 60–100 cm) samples were collected from 11 locations in the beef cattle pasture and four locations in the adjoining natural wetland in the summers of 2002 and 2003 with a hydraulic sinker drill (Fig. 1). The total numbers of sampling sites were based on the actual area of the beef cattle pastures (41 ha) and the adjoining natural wetland (13.7 ha). Locations of sampling sites were permanently marked by using a handheld GPS Unit (Garmin GPS 12 CX, Garmin International, KS) for subsequent soil sampling.

Soil Analyses

Soil samples from the pasture fields were air-dried and passed through a 2-mm mesh sieve before chemical extractions of soil nutrients and analyses. Soil samples that were collected from the adjoining natural wetland were kept at 4°C before soil extraction and analyses. Soil analyses (Mehlich-extractable nutrients, soil organic matter, and soil pH) were conducted at the USDA Agricultural Research Service Laboratory in Brooksville, FL. Analyses of total organic carbon (TOC), nitrogen (TN), and water-soluble P (WSP) were conducted at

the Chemistry Laboratory of the Southwest Florida Water Management District in Brooksville, FL.

Soil pH was determined by using 1:2 soil/water ratio (Thomas, 1996). Double acid-extractable (0.0125 M H₂SO₄ + 0.05 M HCl) Ca, Mg, K, Zn, Cu, Mn, Fe, Al, and Na were extracted as described by Mehlich (1953) and analyzed by using an inductively coupled plasma spectrophotometer. Water-soluble P (WSP) was determined by extracting 5 g soil with 25 mL of deionized water for 1 h. The suspension was centrifuged for 15 min at 2400 rpm and filtered through a 0.45-μm membrane filter. The filtrates were analyzed with a P Auto-analyzer (Kuo, 1996). Total organic carbon and TN in soils were analyzed with a CHN Analyzer (Nelson and Sommers, 1996). Nitrate and nitrite were extracted with 2 N KCl and analyzed with a N Autoanalyzer (Mulvaney, 1996). Soil organic matter (SOM) was analyzed following the Walkley–Black method (Walkley and Black, 1934). Water content was determined according to the method of Gardner (1996). Bulk density was determined by core method (Blake and Hartge, 1996), and particle size was determined following the methods of Gee and Bauder (1996).

Phosphorus Fractionation

Phosphorus sequential fractionation methods were used to identify and quantify different forms of P (WSP, KCl-P, Al-P, CaMg-P, FeMn-P, and Org-P) in both pasture and wetland soils. About 5 g of soil were used to determine P speciation according to the scheme (sequential extraction) shown in Fig. 2. The procedures were slightly modified from previous fractionation schemes that have been used to identify P fractions in wetland soils (Ruttenberg, 1992). Loosely-bound P was extracted with 1 M KCl at pH 7 for 2 h. About 25 mL of 0.1 M Na₂S₂O₄/NaHCO₃ were then added to the soil residue, and the mixture was shaken for 1 h for redox-potential P (FeMn-P). The soil residue was then shaken with 0.1 M NaOH for 16 h to determine the concentration of Al-associated P. About 20 mL of the supernatant was digested with ammonium persulfate to determine the concentration of organic P (USEPA, 1979). The concentration of CaMg-bound P, or apatite P, was extracted with 0.1 M HCl, followed by shaking for 16 h. The different extracts were analyzed following standard procedures (APHA, 1992), using a P Autoanalyzer (Kuo, 1996) immediately after soil extractions.

Data Analysis

The effects of land use on soil profile distribution of P and other nutrients (pooled: 2002 through 2003) following con-

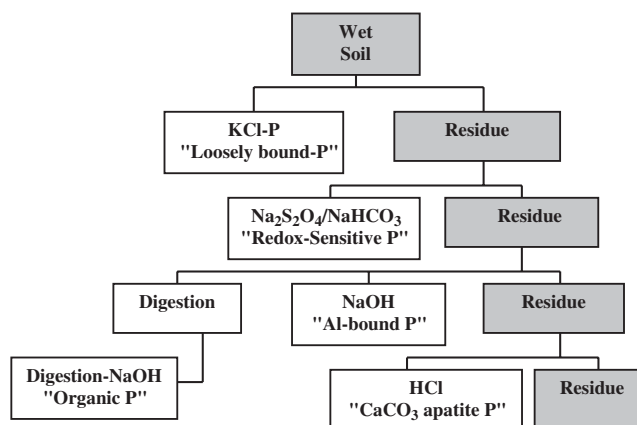


Fig. 2. Sequential fractionation method to determine different forms of P.

version of wetlands to beef cattle pasture were tested for normality and were subsequently analyzed using the procedures of pooled analysis of variance (SAS, 2000) in unbalanced split plot design. Land use (wetland vs. pasture) was the main effect whereas soil depths were the subplot feature. Where the *F*-test indicated a significant ($p \leq 0.05$) soil depth effect, means were separated by least significant differences (LSD) using the appropriate error mean squares (SAS, 2000).

RESULTS AND DISCUSSION

Total Phosphorus and Different Fractions of Phosphorus

Our results did not support our hypothesis that wetland conversion to beef cattle pasture may increase the levels of soil nutrients, especially P. The concentrations of soil TP and all fractions of P were significantly ($p \leq 0.05$)

lower in pastures than in the reference wetland (Fig. 3). Levels of TP, WSP, FeMn-bound P, Organic-bound P, and CaMg-bound P differed significantly with land use by soil depth whereas levels of NH_4 -bound P and Al-bound P were not affected by the interactions of land use and soil depth (Table 1). Wetland soils had higher concentrations (mg kg^{-1}) of Al-bound P (435), apatite P (42), redox-sensitive P (43), and organic-bound P (162) than did pasture soils (172, 11, 11, and 84 mg kg^{-1} , respectively). The levels of WSP and loosely-bound P were comparable between wetland and pasture soils. The mean concentration difference between wetlands and pastures may reflect a decline in TP concentration as a result of wetland conversion to pasture (Fig. 3).

There was a significant ($p \leq 0.05$) decrease in the average concentrations of soil TP with increasing soil depths (0 to 100 cm) in pasture soils, but not in wetland

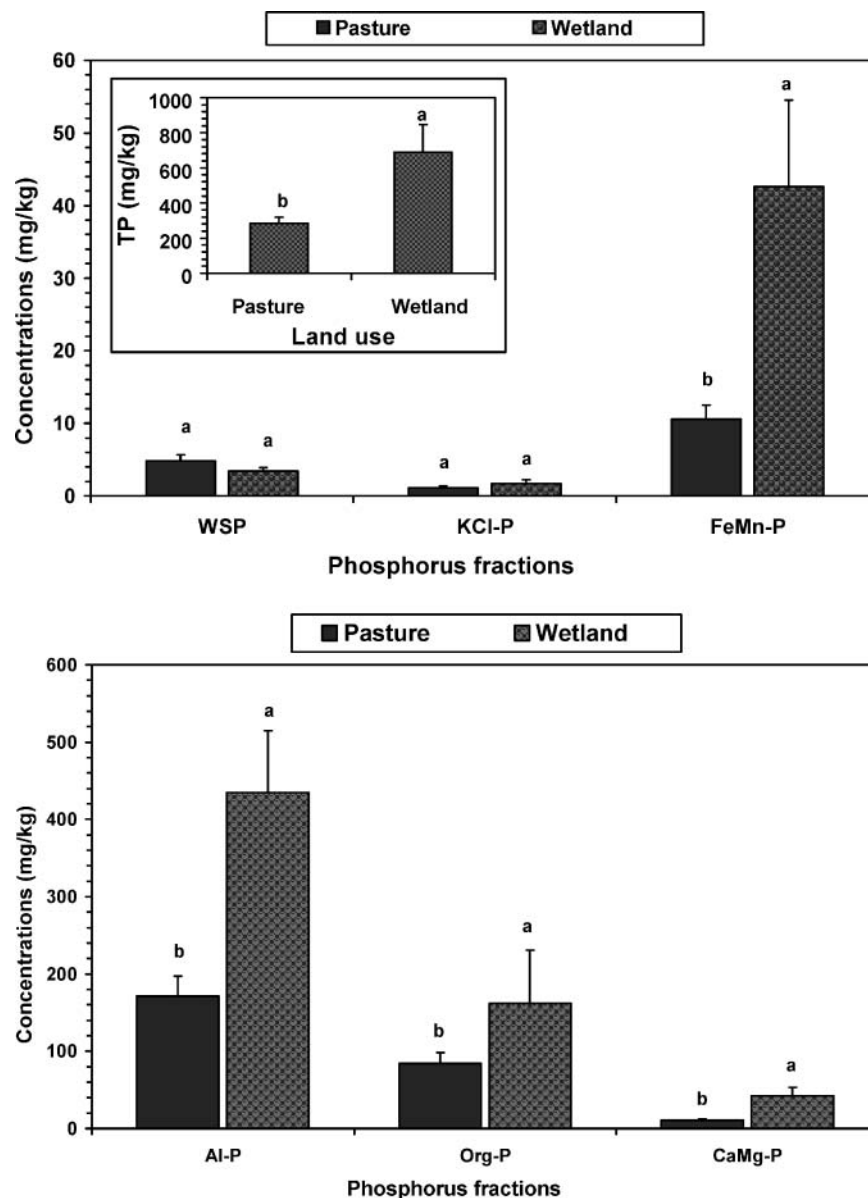


Fig. 3. Comparative levels of the different forms of P between the improved pasture fields and natural wetlands. Forms of P are significantly different ($p \leq 0.05$) when superscripts located at top of bars are different.

Table 1. Levels (mean \pm std. error of mean) of different fractions of phosphorus (pooled: 2002 through 2003) at different soil depths in improved beef cattle pasture and natural wetland.

Depth cm	Phosphorus fractions						Total P
	WSP§	KCl-P	FeMn-P	Al-P	CaMg-P	Org-P	
	mg kg ⁻¹						
	Improved pasture						
0–20	11.4 \pm 1.9a†	2.9 \pm 0.8a	22.9 \pm 5.1a	187.9 \pm 28.7a	22.2 \pm 4.9a	196.8 \pm 30.5a	444.2 \pm 58.9a
20–40	4.1 \pm 0.6b	0.8 \pm 1.2b	7.4 \pm 2.3b	110.9 \pm 20.7a	4.1 \pm 1.1b	57.1 \pm 13.9b	184.5 \pm 30.7b
40–60	2.1 \pm 0.6b	0.3 \pm 0.2b	6.3 \pm 2.7b	158.8 \pm 55.9a	4.6 \pm 1.4b	33.1 \pm 9.6b	205.2 \pm 59.1b
60–100	1.7 \pm 0.6b	0.2 \pm 0.08b	4.8 \pm 1.7b	241.7 \pm 88.7a	11.2 \pm 4.9b	40.8 \pm 25.7b	300.5 \pm 90.2ab
Total	19.4	4.2	41.5	699.7	42.1	327.8	1134.3
LSD (0.05)	3.3	1.4	9.9	ns‡	10.7	65.2	196.9
	Natural wetland						
0–20	3.5 \pm 1.1a	4.3 \pm 0.7a	60.2 \pm 10.4a	369.7 \pm 51.1a	14.1 \pm 2.1a	311.2 \pm 12.9a	762.9 \pm 50.2a
20–40	3.958 \pm 1.1a	1.6 \pm 0.9b	72.4 \pm 48.7a	605.4 \pm 72.9a	31.0 \pm 2.0a	278.9 \pm 72.3a	993.3 \pm 71.8a
40–60	2.9 \pm 0.4a	0.5 \pm 0.3b	18.7 \pm 10.7a	424.9 \pm 41.8a	57.6 \pm 8.4a	31.8 \pm 36.2a	536.4 \pm 74.5a
60–100	2.2 \pm 0.1a	0.5 \pm 0.2b	19.4 \pm 3.7a	344.3 \pm 7.9a	66.1 \pm 3.8a	27.3 \pm 29.3a	459.8 \pm 64.0a
Total	12.6	6.9	170.6	1744.3	168.8	649.2	2752.5
LSD (0.05)	ns	1.9	ns	ns	ns	ns	ns

† Means in columns within land use followed by common letter(s) are not significantly different from each other at $p \leq 0.05$.

‡ ns, not significant.

§ WSP, water-soluble P; KCl-P, potassium-bound P; FeMn-P, iron manganese-bound P; Al-P, aluminum-bound P; CaMg-P, calcium magnesium-bound P; Org-P, organic-bound P.

soils. The average concentration of TP in pasture fields at a soil depth of 0 to 20 cm was about 444.2 ± 58.9 mg kg⁻¹, compared with 300.6 ± 90.2 mg kg⁻¹ at a soil depth of 60 to 100 cm. Except for Al-bound P, all forms of P differed ($p \leq 0.05$) with soil depth in pasture fields, whereas all forms of P except loosely-bound P did not vary with soil depth in the natural wetland (Table 1). Cumulative concentrations of TP in pastures (1134 mg kg⁻¹) are two to three times lower than those in wetlands (2752 mg kg⁻¹) over the periods of land use conversion, suggesting that P release from wetlands may be possible during the process of the conversion (Table 1). Total P declined by 143% in the pasture soil when compared with the level in the natural wetland soil, despite the possible influence of cattle grazing (source of manures and urine) during the 63 yr. Our results suggest that lower content of associated P in pastures seems to be long-term storage mostly held by organic matter and alumino-silicates following establishment of pastures for cattle grazing. Results of correlation analyses confirmed a good relationship ($r = 0.82$) between TOC and organic-bound P for beef cattle pastures (Fig. 4). No other relationships among other forms of P and TOC yielded significant results from beef cattle pastures and wetland soils.

The form of P in improved beef cattle pasture soils was dominated by Al-bound (61.6%) followed by organic-bound (28.9%), CaMg-bound (3.7%), FeMn-bound (3.7%), WSP (1.7%), and KCl-bound (0.4%). The two most dominant forms of P in natural wetlands were the Al-bound (63.4%) and organic-bound (23.6%), followed by FeMn-bound (6.2%), CaMg-bound (6.1%), water-soluble (0.5%), and KCl-bound (0.2%). Results suggest that the forms of soil P were significantly affected by changing land use from wetland to pasture fields after 63 yr. These results are valuable information in determining P exchange potential.

Wetland conversion also influences processes related to the fate and transformation of soil P. The concentra-

tion of WSP in the beef cattle pasture was about 41% lower than that in the adjoining reference wetland. The assumed change in hydrology and subsequent oxidation of surface soils during wetland conversion may oxidize ferrous iron (Fe²⁺) to ferric iron (Fe³⁺). Insoluble ferric oxyhydroxide may precipitate with P, thus binding soluble P under drawdown or drained conditions (Ponnamperuma, 1972; Reddy and Patrick, 1975). The higher concentration of TP in the adjoining reference wetland when compared with the converted wetland in our study was not surprising and our results support that flooding would increase Fe-P. This can be attributed to the pos-

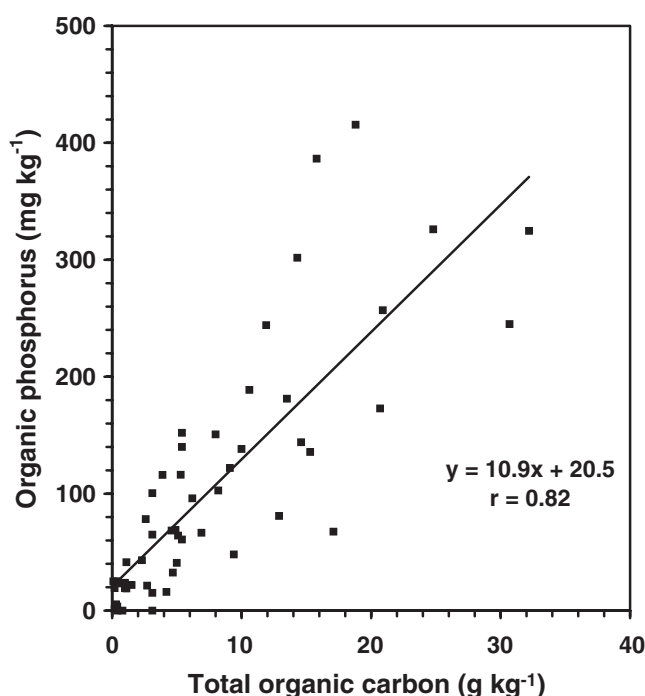


Fig. 4. Correlation analyses showing the relationship between organic-bound P and soil organic carbon in improved beef cattle pastures.

sible transformation of variscite ($\text{AlPO}_4 \cdot 2\text{H}_2\text{O}$) into vivianite [$\text{Fe}_3(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$], the most stable Fe-P mineral under reduced or waterlogged conditions (Lindsay, 1979). Several studies support the idea that flooding would result in the solubilization of P stored in soils and release to the water column (Villapando and Graetz, 2001; Pant and Reddy, 2003).

Total Organic Carbon, Soil Organic Matter, and Soil pH

The average concentration of TOC between the reference wetland and beef cattle pasture declined by about 96% ($180.1 \pm 29.1 \text{ g kg}^{-1}$ to $7.8 \pm 1.2 \text{ g kg}^{-1}$) after 63 yr (Table 2). The average soil pH (across soil depth) of beef cattle pasture (5.92 ± 0.1) was significantly higher than that of soil pH in the adjoining reference wetland (4.14 ± 0.06).

There was a significant land use by soil depth interaction for SOM and for soil pH. The concentration of SOM was sevenfold higher (Table 3) in the wetland than in the pasture systems ($p \leq 0.001$) in the surface soil (0 to 20 cm), but there were no differences below the 20-cm soil depth. The concentration of SOM for both the wetland and pasture soil cores generally decreased with soil depth. Soil pH was significantly affected by changing land use ($p \leq 0.001$), but was not affected by soil depth. Soil pH values for the surface (0 to 20 cm) soil of the adjoining reference wetland and beef cattle pasture were 3.7 ± 0.1 , 4.6 ± 0.0 , and 6.1 ± 0.2 , respectively, and 5.5 ± 0.2 at 60 to 100 cm, respectively (Table 3).

It appeared that conversion of wetland was proceeding toward a soil condition like that of mineral soils. A reduction of TOC and SOM following the conversion of wetland to beef cattle pasture was noted in 2003. Converted pasture conditions promote soil moisture fluctuations that may, in turn, stimulate decomposition and mineralization of organic matter. Faster decomposition of SOM may help maintain the higher base saturation and soil pH. The levels of TOC were $180.1 \pm 29.1 \text{ g kg}^{-1}$ (wetland) and $7.8 \pm 1.2 \text{ g kg}^{-1}$ (pasture), whereas the levels of SOM in the surface soil were $257 \pm 119 \text{ g kg}^{-1}$

Table 3. Levels (mean \pm std. error of mean) of soil organic matter (SOM), pH, and $\text{NH}_4\text{-N}$ (pooled: 2002 through 2003) for the converted pasture and the adjoining reference wetland at varying soil depths.

Depth	Land use	SOM	pH	$\text{NH}_4\text{-N}$
cm		g kg^{-1}		mg kg^{-1}
0–20	pasture	$36.0 \pm 7.8\text{b}^\dagger$	$6.1 \pm 0.2\text{a}$	$0.77 \pm 0.1\text{b}$
	wetland	$257.0 \pm 119\text{a}$	$3.7 \pm 0.1\text{c}$	$2.64 \pm 1.18\text{a}$
20–40	pasture	$18.0 \pm 4.5\text{b}$	$6.1 \pm 0.2\text{a}$	$0.59 \pm 0.05\text{b}$
	wetland	$13.0 \pm 2.1\text{b}$	$4.2 \pm 0.1\text{c}$	$0.51 \pm 1.1\text{b}$
40–60	pasture	$8.0 \pm 1.2\text{b}$	$5.9 \pm 0.2\text{a}$	$0.65 \pm 0.06\text{b}$
	wetland	$5.0 \pm 1.4\text{b}$	$4.4 \pm 0.1\text{c}$	$0.47 \pm 0.10\text{b}$
60–100	pasture	$8.0 \pm 0.9\text{b}$	$5.5 \pm 0.2\text{ab}$	$0.78 \pm 0.08\text{b}$
	wetland	$7.0 \pm 0.7\text{b}$	$4.6 \pm 0.0\text{bc}$	$0.44 \pm 0.01\text{b}$

† Means in columns followed by common letter(s) are not significantly different from each other at $p \leq 0.05$.

(wetland) and $36 \pm 7.8 \text{ g kg}^{-1}$ (pasture). Drying or wetland conversion to agricultural use would lead to mineralization and/or immobilization of stored nutrients because of the changes in soil redox status. Changing soil redox status exerts a strong influence on the microbial community, organic matter mineralization rates, and mineral equilibrium (Ponnamperuma, 1972; Rowell, 1981). Organic matter decomposition under drained conditions proceeds from two- (Reddy and Patrick, 1975) to three-fold (DeBusk and Reddy, 1998) faster than under flooded conditions. In the absence of molecular oxygen (O_2), such as under flooded soil conditions, other soil nutrient electron acceptors, such as nitrate (NO_3^-), ferric iron (Fe^{3+}), manganic manganese (Mn^{4+}), sulfate (SO_4^{2-}), and carbon dioxide (CO_2) are used to satisfy microbial respiratory requirements at a low energy value.

The average pH of the pasture field was higher (less acidic) than that of the reference wetland, and our results were consistent with those obtained by Reiners et al. (1994) and Anderson (1987). Reiners et al. (1994) reported that grazed pastures are less acidic and have lower conductivity. Early work of Anderson (1987) has shown that soils are increasingly acidic in areas with increasing wetness (e.g., wetlands, landscape depressions). Statistical relationships between base saturation and the proportion of the exchange complex occupied by acidic cations such as Al or H indicate a general decrease in base saturation with increasing moisture.

Total Nitrogen and Ammonium-Nitrogen

The concentration of TN (Table 2) and ammonium-nitrogen ($\text{NH}_4\text{-N}$) was significantly ($p \leq 0.001$) affected by the interaction of changing land use and soil depth. The concentrations of soil TN and $\text{NH}_4\text{-N}$ (Table 2) in the beef cattle pasture (0.7 ± 0.1 and $0.7 \pm 0.03 \text{ g kg}^{-1}$, respectively) were significantly lower than those in the adjoining reference wetland (10.8 ± 11.1 and $10.8 \pm 11.1 \text{ g kg}^{-1}$, respectively). Our data further confirm that draining a wetland influences processes related to the fate of N. The mean concentration of $\text{NH}_4\text{-N}$ in the converted pasture ($0.7 \pm 0.03 \text{ mg kg}^{-1}$) was significantly lower than that in the adjoining natural wetland ($1.2 \pm 0.2 \text{ mg kg}^{-1}$). One of the reported characteristics of flooded soil is an increase in the concentration of $\text{NH}_4\text{-N}$ in soil pore-water (Patrick and Mahapatra, 1968). Anaerobic soil con-

Table 2. Comparative levels (mean \pm std. error of mean) of selected soil properties between the converted pasture ($n = 88$) and the adjoining reference wetland ($n = 32$). †

Soil chemical property	Unit	Improved pasture	Natural wetland
TOC §	g kg^{-1}	$7.8 \pm 1.2\text{b}^\ddagger$	$180.1 \pm 29.1\text{a}$
TN	g kg^{-1}	$0.7 \pm 0.1\text{b}$	$10.8 \pm 1.7\text{a}$
pH	pH unit	$5.92 \pm 0.1\text{a}$	$4.14 \pm 0.06\text{b}$
$\text{NH}_4\text{-N}$	mg kg^{-1}	$0.7 \pm 0.03\text{b}$	$1.2 \pm 0.2\text{a}$
K	mg kg^{-1}	$2.6 \pm 0.2\text{b}$	$3.3 \pm 0.5\text{a}$
Ca	mg kg^{-1}	$168.5 \pm 1.9\text{a}$	$80.1 \pm 1.5\text{b}$
Mg	mg kg^{-1}	$11.6 \pm 1.8\text{a}$	$4.1 \pm 0.5\text{b}$
Zn	mg kg^{-1}	$1.1 \pm 0.2\text{a}$	$0.6 \pm 0.07\text{b}$
Mn	mg kg^{-1}	$0.4 \pm 0.06\text{a}$	$0.1 \pm 0.009\text{b}$
Cu	mg kg^{-1}	$0.2 \pm 0.06\text{a}$	$0.01 \pm 0.003\text{b}$
Fe	mg kg^{-1}	$9.4 \pm 1.3\text{a}$	$2.5 \pm 0.2\text{b}$
Al	mg kg^{-1}	$358.5 \pm 35.6\text{b}$	$488.9 \pm 24.9\text{a}$
Na	mg kg^{-1}	$18.3 \pm 0.5\text{a}$	$19.9 \pm 0.6\text{a}$

† Pooled data (year and soil depth combined for each land use type).

‡ Means in rows followed by common letter(s) are not significantly different from each other at $p \leq 0.05$.

§ TOC, total organic carbon; TN, total nitrogen.

Table 4. Levels (mean \pm std. error of mean) of soil water-soluble P (WSP), K, Ca, Mg, and Na (pooled: 2002 through 2003) for the converted pasture and the adjoining reference wetland at varying soil depths.

Depth	Land use	WSP	K	Ca	Mg	Na
cm						
—mg kg ⁻¹						
0–20	pasture	5.6 \pm 1.1a†	4.2 \pm 0.4b	241.5 \pm 29.7a	8.5 \pm 1.2b	18.1 \pm 1.1a
	wetland	9.4 \pm 0.7a	7.8 \pm 1.8b	138.4 \pm 63.6abc	7.4 \pm 3.1b	23.5 \pm 3.6a
20–40	pasture	5.5 \pm 1.4a	2.2 \pm 0.3c	147.1 \pm 14.7abc	3.7 \pm 0.5b	17.9 \pm 0.8a
	wetland	12.6 \pm 2.5a	1.2 \pm 2.9c	43.2 \pm 17.1c	1.9 \pm 0.6b	18.1 \pm 1.3a
40–60	pasture	5.8 \pm 1.5a	1.6 \pm 0.2c	114.6 \pm 10.8bc	7.1 \pm 1.9b	17.9 \pm 0.9a
	wetland	9.7 \pm 0.6a	1.3 \pm 0.3c	60.7 \pm 3.1c	2.6 \pm 0.1b	18.3 \pm 0.6a
60–100	pasture	7.5 \pm 1.7a	2.1 \pm 0.4c	170.8 \pm 22.6ab	26.9 \pm 3.9a	19.4 \pm 2.9a
	wetland	10.6 \pm 1.3a	1.1 \pm 0.1c	72.1 \pm 0.1bc	4.9 \pm 0.1b	19.8 \pm 0.4a

† Means in columns followed by common letter(s) are not significantly different from each other at $p \leq 0.05$.

ditions prevent nitrification; consequently, more N in the form of $\text{NH}_4\text{-N}$ accumulates in wetland soils. The lower concentration of N in the beef cattle pasture was likely the result of changes caused by draining and nutrient cycling. First, aerobic conditions would promote nitrification. Second, uptake of available N would have increased substantially due to extensive growth of bahiagrass. Nutrient cycling may also be a factor. Floate (1970) reported that a considerable proportion of N in cattle excreta is not really recycled to the soil in pasture systems for various reasons: (a) part accumulates in stock camping areas rather than being spread over the pasture; and (b) much of the N remains near the surface and volatilizes during dry periods, even before being leached into the root zone.

Potassium, Calcium, Magnesium, and Sodium

Mehlich-extractable Ca and Mg were about 110% and 185% greater ($p \leq 0.001$), respectively, and K was 21% lower ($p \leq 0.05$) in pasture than in adjacent wetland, (Table 4 and Fig. 5). Our results support the idea that Ca and Mg solubility are greater under oxidizing conditions (Gilliam et al., 1999). The higher concentration of Ca and Mg in the converted pasture could be attributed to the application of lime (3.4 Mg ha⁻¹ dolomitic limestone once every 3 yr). The use of lime can be important for increasing the concentration of Ca in the soil

or managing the balance between Ca and Mg. The interaction for Ca among depths and land use was more difficult to describe. In wetlands, the surface layer contained more Ca than those from 20 to 60 cm, but was not different from the 60- to 100-cm layer. Concentration of Mg was higher in the lowest horizon (60 to 100 cm) for the pasture, but was not different among the other treatment \times soil depths (Table 4).

The concentration of Na was not affected by land use change and was not different through the profile. Soil Ca, Mg, and K levels in both pasture and wetlands were different ($p \leq 0.05$) among depths, but trends could not be established. The interaction of land use \times soil depth was significant for K, but not for Ca and Mg. Higher ($p \leq 0.05$) concentrations of K were observed in the surface layer (0 to 20 cm) of the wetland soil than in the pasture soil, and these concentrations were higher than for those at other depths (Table 4), which were similar between land use treatments. The average soil test values of K (0 to 20 cm) for improved pasture of 2.6 ± 0.2 mg kg⁻¹ and 3.3 ± 0.5 mg kg⁻¹ for wetland were low in 2003 (Table 2). At these levels of K, the bahiagrass would have been extremely K deficient. Considering that the concentration of K in the soil was consistently low in both the pasture and wetland, the low soil test values for K in the pasture may have been a temporary effect of no K fertilization since 2001. Since K-contain-

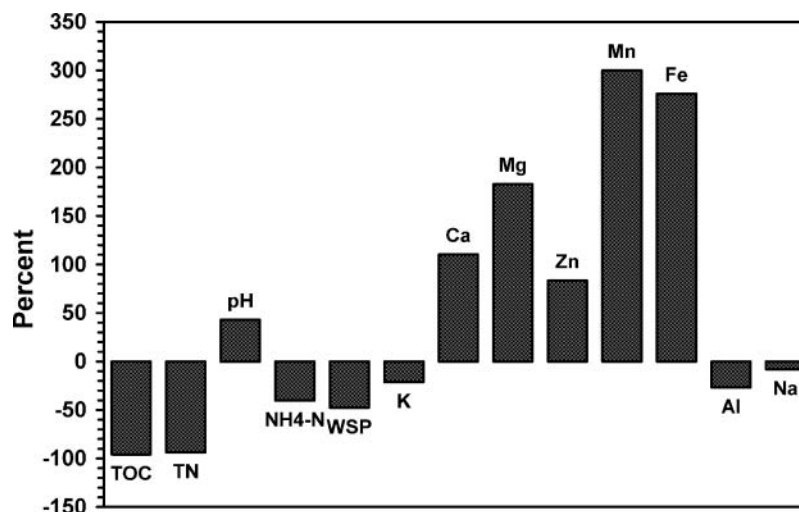


Fig. 5. Relative difference (%) in the concentrations of soil nutrients (water-soluble P (WSP), total nitrogen (TN), K, $\text{NH}_4\text{-N}$, Ca, Mg, Zn, Mn, Fe, Al, and Na), levels of soil pH, and soil total organic carbon (TOC) as a result of converting natural wetlands to improved beef cattle pasture field (1940 through 2003).

Table 5. Concentration (mean \pm std. error of mean) of soil Zn, Mn, Cu, Fe, and Al (pooled: 2002 through 2003) for the converted pasture and the adjoining reference wetland at varying soil depths.

Depth	Land use	Zn	Mn	Cu	Fe	Al
cm		mg kg ⁻¹				
0–20	pasture	1.2 \pm 0.1a†	1.02 \pm 0.1a	0.18 \pm 0.1a	5.6 \pm 1.4b	332.3 \pm 76.5a
	wetland	1.1 \pm 0.5a	0.16 \pm 0.1b	0.01 \pm 0.01a	2.6 \pm 1.1ab	440.6 \pm 170a
20–40	pasture	0.5 \pm 0.1a	0.28 \pm 0.1b	0.04 \pm 0.1a	6.1 \pm 4.6ab	402.8 \pm 63a
	wetland	0.3 \pm 0.1a	0.06 \pm 0.3b	0.01 \pm 0.01a	1.4 \pm 0.4b	485.1 \pm 123a
40–60	pasture	1.1 \pm 0.4a	0.13 \pm 0.03b	0.13 \pm 0.1a	11.7 \pm 2.8ab	379.8 \pm 78.3a
	wetland	0.3 \pm 0.4a	0.09 \pm 0.0b	0.001 \pm 0.01a	2.7 \pm 0.4ab	552.5 \pm 56a
60–100	pasture	1.8 \pm 0.8a	0.14 \pm 0.03b	0.33 \pm 0.2a	14.3 \pm 2.8a	319.2 \pm 65a
	wetland	0.6 \pm 0.1a	0.09 \pm 0.1b	0.04 \pm 0.01a	5.8 \pm 0.1ab	443.0 \pm 60a

† Means in columns followed by common letter(s) are not significantly different from each other at $p \leq 0.05$.

ing fertilizer was being applied to the pasture field once every 3 yr, bahiagrass could have taken most of the available K from the soils, leaving the soil with low levels of K, especially during years with no K fertilization. Sigua et al. (2004, 2005) also observed and reported low levels of Mehlich K in soils with no K fertilization (control plots) from surrounding beef cattle pastures with bahiagrass. Periodic applications of additional K may be necessary to satisfy the K requirement of bahiagrass in pastures with similar soil types.

Zinc, Manganese, Iron, Aluminum, and Copper

Land use and soil depth did not affect the concentration of Zn, Al, and Cu. The concentration of Mn in the surface soil of pasture was approximately fivefold higher than in the wetland soil; however, Mn concentrations did not change with profile depth (Table 5). The Fe concentration in the soil varied with both land use and soil depth ($p \leq 0.001$), but not by the interaction of land use and soil depth. The concentration of Zn, Cu, and Al in the pasture soils did not differ with soil depth, whereas Zn, Mn, and Al concentration did not show any significant trend with soil depth in the adjoining reference wetland (Table 5).

CONCLUSION

Conversion of wetland to beef cattle pastures may affect soil profile distribution of P, soil organic carbon, and other soil nutrients. The concentration of TOC and SOM in the converted pasture soil was 96 and 86% less, respectively, when compared with the concentration of TOC and SOM in the soil from the wetland. It appeared that conversion of wetland was proceeding toward a soil condition or composition like that of mineral soils. The levels of Zn, Cu, Al, and Na in soils from the converted pasture were similar to those in the adjoining wetland. These results are important in establishing useful baseline information on soil properties in pasture and adjoining wetland before restoring and converting pasture back to its original wetland conditions. Our results suggest that conversion of wetland to beef cattle pasture was not environmentally detrimental because the levels of soil nutrients, especially P and N, which in the improved pasture both showed decreasing trends after 63 yr. The results further suggest that changes in soil properties due to changing land use could be long lasting.

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